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Forest chips for energy in Europe: Current procurement methods and potentials

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ABSTRACT

Forest chips are becoming an important alternative resource for energy in Europe. The aim of this study is to review and analyze the current procurement methods and potentials of forest chips in Europe, based on questionnaires sent to relevant experts in different countries as well as a literature review of existing literature. The compilation of current uses of wood chips and existing procurement methods was based on data from several professionals in 17 countries. The analysis of the forest chips potentials by countries combined data supplied by the experts as well as additional sources based in the literature. The results showed that Finland and Sweden use the largest volumes of forest chips, and is expected that many other countries will experience a significant increase in the use to produce energy. Currently, the main source of forest chips in most of the countries are logging residues, but in the near future it is expected a shift towards increasing utilization of stumps and roundwood. In the EU, the estimates for biomass potential for energy available under current conditions were 277 M m^3, for above ground biomass and 585 M m^3 for total biomass. The total long term potential is estimated to be 913 M m^3. The results of this study reveal that significant volumes of forest chips are used in most of the selected countries for energy and the experts consulted as well as the literature suggests that even larger volumes can be mobilized and novel technology developed to improve the efficiency of supply.

Contents

1. Introduction

The use of wood for energy in industrial scale has become increasingly important in the last years. The necessity of new ways of energy production, the effects of climate change, the increasing dependency on energy imports from insecure regions

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and the rising prices for fossil fuels cause that modern fuelwood come back in the focus of society [1].

The European Union is aware that energy is fundamental to the functioning of Europe but also that the energy has to become from renewable sources. Several targets were proposed by EU to push the countries to attach new renewable objectives. For example in the Road Map, the Commission proposed setting a mandatory target of 20% for the share of renewable in energy consumption in the EU by 2020. All of this means that EU countries in the last years have been developing the use of renewable energy sources and primary residues from forest have become an important renewable energy source.

The use of fuelwood is very important for all the countries, not only for the ones with more developed wood sector. Biomass from forest for energy represents a great opportunity to publicize and promote the forest in countries with lack of forest culture due to the utilization of wood for energy depends highly of the availability of local forest biomass resources [2]. Therefore the use of low-quality biomass for energy, like wood from pre-commercial thinnings, is good for silviculture treatments because it promotes the management of young forests. The use of removal of logging residues and stumps as fuelwood could be a way to develop post-harvesting management practices [3]. In Finland, mechanized planting has become competitive largely due to harvesting of logging residues and stumps [4].

Different studies have already been carried out in order to estimate the resources of biomass for energy and the use of these sources, showing that in practically all EU countries the energy use from biomass is less than the resources [5]. Potential data of fuelwood have been studied in reports like [6–9], estimating the energy potentials in European Union and in a world level. The main producers are logically those countries that possess the largest territories and the biggest forestry countries of Northern Europe. In this way, the five leading producer countries (France, Sweden, Germany, Finland and Poland) represent 58% of primary energy production coming from solid biomass [10]. However, when interpreting the studies of forest energy potentials, one must bear in mind that there can be very large differences between different studies with respect to the potentials due to different geographical focuses, methodologies, constraints, scenario assumptions, and biomass categories [11].

Data, guidelines and studies about the current and potential situation in the procurement of forest chips, are difficult to find at country level, if they exist at all. Because of that, country experts in the topic area and at local level, are the best and sometimes the only source of information. Obtaining data through an expert allowed formulating questions using technical language and ensuring an accurate and concise respond and in consequence valid study results.

There is a certain lack of research concerning the biomass procurement methods, current figures and potential sources of wood chips for energy, especially in the countries that are currently developing this sector. The aim of this paper is to analyze the current situation of the procurement of forest chips for energy in Europe. This consist mainly in the analyses of the present use of forest chips, the sources and technology and systems used to supply forest chips, the potential of forest chips, tree species used in each country and prices of forest chips.

2. Material and methods

2.1. Origin of data

The data were collected through two steps. First, a literature review was conducted aiming at finding information about the present situation of forest chips recovery for energy in different EU countries. For the review studies from academic literature and published reviews and papers, from international agencies (including, among others: IEA, FAO FRA 2010 Country Reports, Global Forest Resources Assessment, UNECE and METLA) were considered. Second, based on the literature review, a database of experts in bioenergy issues was prepared, which resulted in 63 professionals from 23 countries. These experts were consulted through an online survey about procurement of forest chips for energy in the countries considered. The survey was undertaken between November 2009 and May 2010, with a second round in November–December 2012. The interviewees were first contacted though e-mail, and asked to fill the questionnaire with a brief explanatory letter about the survey objective. In addition to that, the questionnaires were also sent in paper form, when demanded. (The complete list of experts and positions is available upon request).

The structure of the questionnaire consisted in 16 questions divided in 8 sections: personal data, existing guidelines/studies on recovery rate, present use of forest chips, potential of forest chips, procurement chain, trees species composition, price of forest chips, and present use of solid wood fuels.

All the questions were designed to be understood by experts in the field, using appropriate established terminology, or clarifications when needed. The questionnaire was provided with some examples concerning the Finnish situation, in order to guide the interviewee.

The procurement of forest chips was divided in 6 types of sources along the entire questionnaire: Logging residues from final fellings, whole trees or pre-commercial stemwood (from pre-commercial thinning), industrial roundwood from final fellings, industrial roundwood from thinnings, roots and stumps from final fellings and other forest biomass. All the questions were referenced to these sources.

After the questionnaire was submitted, the interviewees were asked to send complementary guidelines and studies of procurement of biomass; in case they cited them in questionnaire. After a preliminary analysis of the data, further correspondence was sent in order to obtain more information or clarifications.

2.2. Data analysis

The data collected were firstly analysed quantitatively by using statistical tools such as frequency tables and data descriptors. Part of the collected data were transformed by average conversion factors in order to standardise the results being aware that this values may change with the different species, wood type, age, site and moisture content among other factors: e.g., 1 solid $m^3=415$ kg at medium density and 1 green $t=0.5$ o.d.t [12], 1 solid $m^3=7.2$ GJ (assumption: 1 $m^3=2$ MW h$=7.2$ GJ) [9].

Attending to the sources of raw materials, the classification was modified in the referenced data, considering together the categories of whole trees from pre-commercial thinnings and industrial roundwood from final fellings and thinning, and without the categories of other biomass and unknown sources, in order to be able to compare the experts' information to the existing literature.

Concerning the potentials for forest chips, the literature was organized in three main scenarios:

Ia) above ground biomass, current conditions: based on the expert estimates, Asikainen [7] and Anttila [8], upper estimates.
Ib) total biomass, current conditions: based on Asikainen [7], Karjalainen [6] and Verkerk [9], estimates 2010.
II) total biomass, highest potential: based on Karjalainen [6], using all the potential wood growth not currently used.

The units were all converted to annual M m^3 when necessary. The different methodologies used to estimate the potentials were

Table 1
Methodologies used in the literature to calculate the potentials for forest chips.

Resource	Asikainen [7]	Anttila [8]	Karjalainen [6]	Verkerk [9]
	FAO 2006 (commercial growing stock and NAI)	FAO 2006 (commercial growing stock and NAI)	FAO 2000 (commercial growing stock and NAI)	Country NFI (growing stock and NAI) and forest area available for wood supply
Potential includes				
Other forest biomass	✓	✓		✓
Logging residues from roundwood removals	✓	✓	✓	✓
Annual change rate of growing stocks	✓	✓	✓	✓
Logging residues from supplementary cuttings		✓		
Stumps and coarse roots	✓		✓	✓
Methodology				
Logging residues calculations				
Share of biomass components divided by species groups	✓		✓	
Amount of industrial roundwood removals and unmerchantable stemwood as a percent of the roundwood removals. Transformed with BEF (Biomass Expansion Factor) applied by specie, group and climatic zone.		✓		
Model (EFISCEN) considering age and species, with biomass allocation factors, in a specific period of time				✓
Constrains				
Technical	✓		✓	✓
Recovery rate	✓		✓	
Harvestable areas for stumps	✓		✓	
Socio-economic				✓
Environmental				✓
Different scenarios of mobilization				✓
Complementary fellings				
25% of the annual change rate surplus (surplus of merchantable roundwood that could be use for fuelwood)	✓	✓	✓	

taken into account (Table 1) in order to make the data comparable. For every scenario, averages where constructed and displayed as maps. Finally, the estimates from the different sources were compared in order to assess the degree of agreement between the different sources and the experts consulted.

3. Results

3.1. Responses

Countries identified in the literature review with a weak development of the industry of forest chips, or that did not answer significant parts of the questionnaires were excluded from further analysis. After filtering the data, information about the procurement, current uses and potentials from 17 countries were retrieved from the questionnaires and the literature provided (Fig. 1).

The questionnaires were only partially filled, with answers for less than 60% of all the questions in the case of Austria, France, Germany, Italy, Ireland and United Kingdom. The rest of the experts filled over 70% of the questions requested.

In addition, the experts contributed to expand the literature review by adding supporting material to their estimates (Table 2). From the review, only five countries were found with official guidelines published concerning the procurement of forest biomass for energy, and studies on the actual recovery rate of forest biomass for energy.

Fig. 1. Distribution of the experts consulted, by countries.

3.2. Current uses of wood chips

According to the results, the countries with the highest current use of forest chips were Sweden, Finland, Estonia and Austria (Fig. 2). Some of the experts did not supply estimates about current use of forest chips (Germany, Italy and Spain), although reported that despite the no availability of national statistics (e.g., for Spain), they assumed a short term increase as there are power plants under construction.

The main source used in all the countries to produce forest chips for energy were the logging residues, representing the 36% of the sources of forest chips, and whole trees or stemwood from pre-commercial thinning representing 19% of the sources (Fig. 2). The exceptions were Denmark, Ireland and Spain, where the most dominant sources were whole trees, particularly stemwood from

Table 2
Main sources of the secondary analysis used in the study. Some of the references were supplied by the experts consulted, as main references for the analysis.

Part of the analysis	Country	References retrieved
Guidelines and studies	Denmark	[13,14]
	Finland	[15,16]
	Italy	[17]
	Latvia	[18,19]
	Sweden	[20]
Present use of forest chips for energy	Austria	[21]
	Denmark	*
	Estonia	*
	Finland	[22,23]
	France	*
	Ireland	[24]
	Latvia	[25]
	Netherlands	[26]
	Norway	[27]
	Poland	*
	Slovakia	[28]
	Sweden	*
	UK	[29]
Current prices of forest chips	Austria	*
	Denmark	*
	Finland	*
	Italy	*
	Latvia	*
	Norway	*
	Poland	*
	Slovakia	*
	Spain	*
	Sweden	*
Country potentials of forest chips for energy	Denmark	[30]
	Estonia	[31]
	Finland	[32–34]
	Germany	[35]
	Latvia	*
	Netherlands	[26]
	Norway	[36]
	Poland	*
	Slovakia	[37]
	Spain	[38]
	Sweden	[39]
European potentials of forest biomass for energy	EU27	[7]
	EU27	[8]
	EU25	[6]
	EU27	[9]

* Data based on expert's own estimates.

pre-commercial thinnings and industrial roundwood from thinnings. In many of the countries there were not available studies or official statistics to determine the sources for forest chips for energy, and therefore the data was based in the experts' knowledge.

Concerning the species most commonly used, only a few experts reported estimates due to the absence of official statistics. The data retrieved reflect the different commercial species in the different climates (Table 3).

A great variety of supply chains and operations concerning the procurement of the wood chips were identified (Fig. 3). These chains represent the main sequence of operations based on the analysis, although there were reported alternatives: e.g., in Poland most of the felling/cutting are doing by harvester, but in about 5% of the cases the operation is manual, and in the phase forwarding/skidding is mostly used forestry-fitted farm tractor but in the 15% of the cases is done by forwarder and in 5% is by man or animal power.

In general, the most extended procurement chain for logging residues from final fellings, uses felling/cutting by harvester, forwarding/skidding by forwarder, chipping/crushing at the road-side and transportation by truck. This system is applied in Estonia, Finland, Germany, Latvia and Sweden. Only in United Kingdom wood is chipped at plant, and only in Norway at the terminal. In Poland and Denmark it is usually chipped at the stand, and in the rest of the countries at the roadside. In United Kingdom, the extraction of residues is mostly carried out by baling residues on site (mostly on clear fell sites) and then extracted to roadside by forwarder, loaded on trucks and transported to the power plants, where they are chipped.

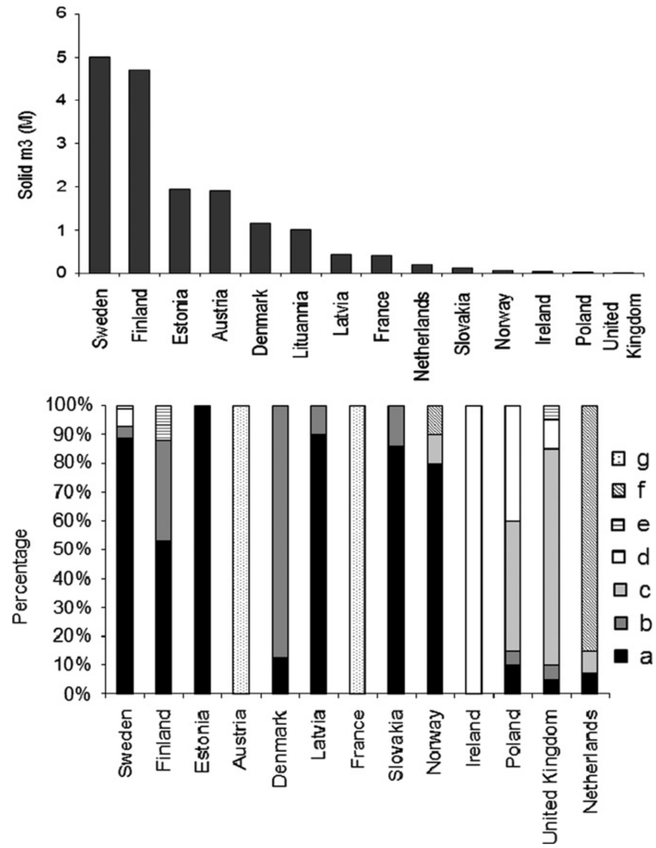

Fig. 2. Total estimated current uses of wood chips for bioenergy (up) and by source (bottom). (a) Logging residues from final fellings, (b) Whole trees/pre-commercial stemwood from precommercial thinning, (c) industrial roundwood from final fellings, (d) industrial roundwood from thinnings, (e) stumps and roots from final fellings, (f) other forest biomass, (g) unknown.

Table 3
Estimates of shares of the different species used as raw material for wood chips for energy.

Source	Country	*Picea abies* (%)	*Pinus sylvestris* (%)	*Betula spp.* (%)	Other pine (%)	Other deciduous
Logging residues	Denmark	80			20	
	Finland	75	25			
	Latvia	40	20			40
	Norway	90		10		
	Poland	10			80	10
	Sweden	65	25			10
Pre-commercial thinnings	Denmark	100				
	Finland	10	40			50
	Poland	3			90	7
	Sweden	10	40	30		
Industrial roundwood from final fellings	Norway	15			15	70
	Poland	5			65	30
	Poland	5			85	10
	Sweden	20	50	30		
Stumps and roots from final felling	Finland	100				
	Sweden	75	25			
Other forest biomass	Sweden	60	20			

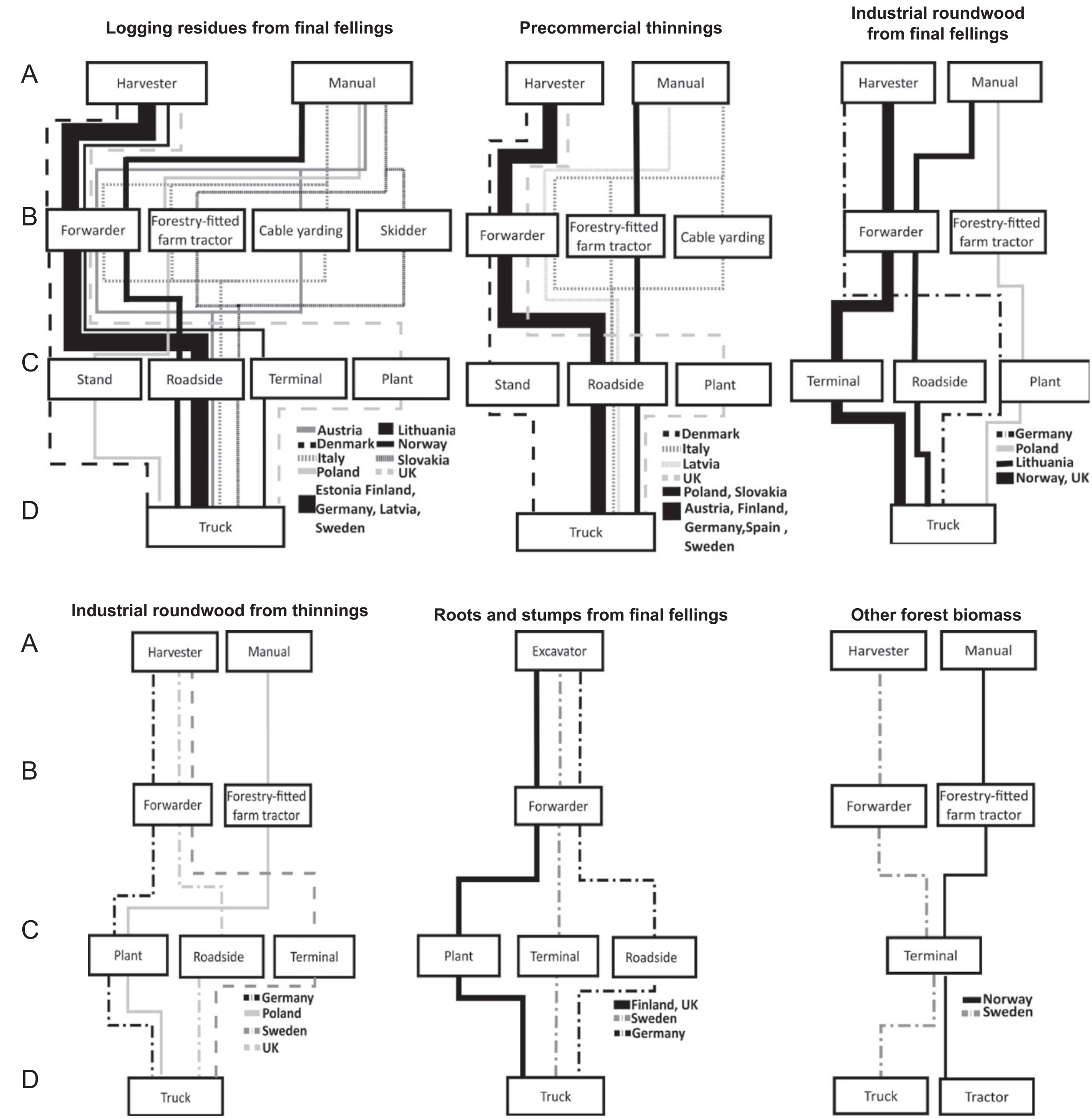

Fig. 3. Supply chains. (A) Felling/cutting, (B) off-road transport, (C) chipping/crushing, (D) road transport.

Seven countries reported not using at the present raw material from pre-commercial thinnings as a forest chips source. In the rest of countries the most typical procurement chain for pre-commercial thinning, are felling/cutting by harvester, forwarding/skidding by forwarder, chipping/crushing at the roadside and transportation by truck.

In Denmark, whole trees are chipped in the stand or in some cases at roadside. Energy roundwood is chipped at roadside or at mill but in the interviewed person opinions industrial roundwood is not used for energy. Also in this case, United Kingdom performs the chip/crushing at the plant. In Italy for felling/cutting also use harvester, but only in about 5% of the operations.

Concerning industrial roundwood from final fellings, the most typical procurement chain, for the five countries that use this source, is felling/cutting by harvester, forwarding/skidding by forwarder, transportation by truck and chipping/crushing at the terminal. About industrial roundwood from thinning, the procurement chain for industrial roundwood from thinnings is different in the four countries that use this source. Two of the countries chipped at the plant, one of the others at the roadside and the other at the terminal.

Concerning other sources of biomass as roots and stumps from final fellings, only four countries consider their use to produce forest chips for energy. In Finland and United Kingdom follow the same procurement chain, in Germany chipping is done at the roadside and in Sweden crushing is performed at the plant or at

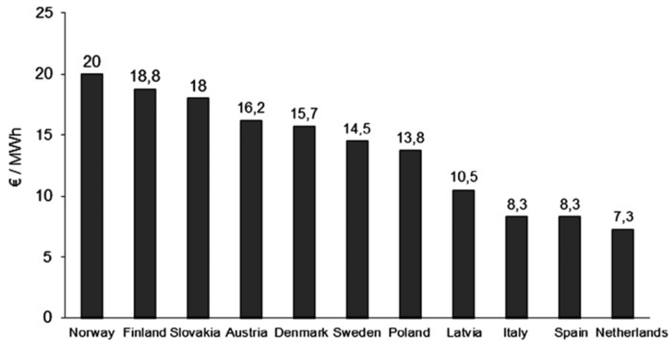

Fig. 4. Country estimates of average prices for forest chips at plant, based on the expert's responses.

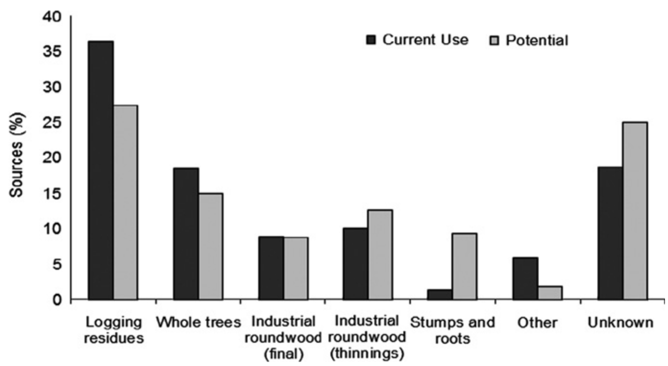

Fig. 5. Comparison of the sources of raw material of wood chips for energy for estimated current use and potential.

the terminal. In this case, the experts reported that roadside crushing seems to be an interesting option and may increase.

Other forest biomass sources are considered in some countries. In Sweden is substandard roundwood, although it was not considered as a percent of the present use, and in Norway whole trees from roadside cleaning and other landscape management activities. Both are chipped at the terminal but follow different procurement chains.

Finally, they were reported estimated of the average prices for wood energy chips at plant in the different countries, showing wide ranges from 20 EUR/MW h in UK to 7.3 EUR/MWh in Netherlands and 8.3 EUR/MW h in Spain and Italy (Fig. 4).

3.3. Forest chips potentials

The results in the potential of forest chips show changes both in the proportions and in the sources comparing with the present use (Fig. 5). There were no official statistics to further determine the potential sources of forest chips for energy, and the estimates were based on the expert calculations, which provided some additional references concerning studies.

The experts consulted provided estimates of potential for eleven of the countries analyzed. The results showed that also the most common source for the potential is logging residues from final fellings, although in general the share would become comparatively lower than currently. The main differences concern the increase of industrial roundwood from thinnings and stumps although it must be taken into account that the rate of answers in the potential of forest chips are smaller than in the present use.

In Estonia, the expert consulted provided the data of the theoretical long-term average annual yield of forests, taking into account harvesting residues and stumps, although it was not included the technical potential. As currently Estonia presents large areas of mature stands, it means that larger quantities of wood fuel can be available. The actual use of the resources will then depend on the situation in the wood market.

The total estimated potential uses of wood chips for bioenergy by source differ in some of the cases (Fig. 6). One example is Denmark; in the proportion of the source stems is 70% and 45% higher than in the literature. Some other categories were considered, e.g., in Latvia 2% of the potential was estimated to result from undergrowth trees, 6% from residues from industrial roundwood from thinnings, 1% from forest infrastructures and 13% from naturally afforested lands.

Finally, the average estimates in the EU, for current conditions above ground biomass available (scenario Ia), resulted in 277 M m^3 available (no data for Greece). For total current biomass available (Ib) was estimated to be 585 M m^3, and the total potential (II) was estimated to be 913 M m^3 (Fig. 7). The data showed the highest values for Germany, Sweden, Finland and France. There was a considerable agreement in the estimates for potential above ground biomass resulting from the sources included (experts and different literature estimates). In most of the cases the differences were below 20% of the average (Fig. 8), although notable deviations were found in countries such Poland, Spain. Higher deviations were found concerning estimates for total biomass potentials, in this case only considering literature sources. In the most extreme case (Romania) the differences were almost double than the average.

4. Discussion

The present research aims at analysing the potentials and current situation of procurement of forest chips for energy in Europe. The use of forest chips for energy as a renewable energy has been increasing in the recent last years and it is expected to continue in the near future. The use of modern fuelwood has experienced large efficiency improvements [8] and currently most of the biomass used for energy in the EU is wood.

Nowadays, there are existing compilations for estimates of the amounts of woody biomass from forests and outside forests that are used for energy production in different sectors, e.g., the Joint Wood Energy Enquiry [40]. However, there is a lack of official statistics concerning the present utilization, and particularly concerning the harvesting, chipping and transport technology of wood chips for energy. The use of experts from different countries is a valid first step to provide data in order to have a clear image of the situation of the field and the future potentials. Local experts can access to sources of information that are subject to different barriers (e.g., linguistic) and have a more accurate knowledge of the present conditions of the field.

At the same time, there are obvious limitations in the data used in the study. In some cases, especially concerning the procurement chains, there were some misunderstanding concerning the methodology and terminology, and further clarifications had to be provided. The percent of answers of the total sample was high, but the data provided was in many cases incomplete, as some experts were not able to provide with supported data for some of the questions. This means that there is not enough data to make a complete analysis at all levels for all Europe, although the countries analysed are a valid sample representing the most advanced countries in the bioenergy sector.

In general, the questionnaires provided with figures as well as references supporting the estimates. However, in some cases the figures reported were based in the expert's experience, as there were no available published documents. Furthermore some of the data retrieved had to be analyzed with caution, e.g., the potential of forest chips in Estonia for the year 2008 was 1.763 M solid m^3, which is already lower than the present use data provided by the interviewed

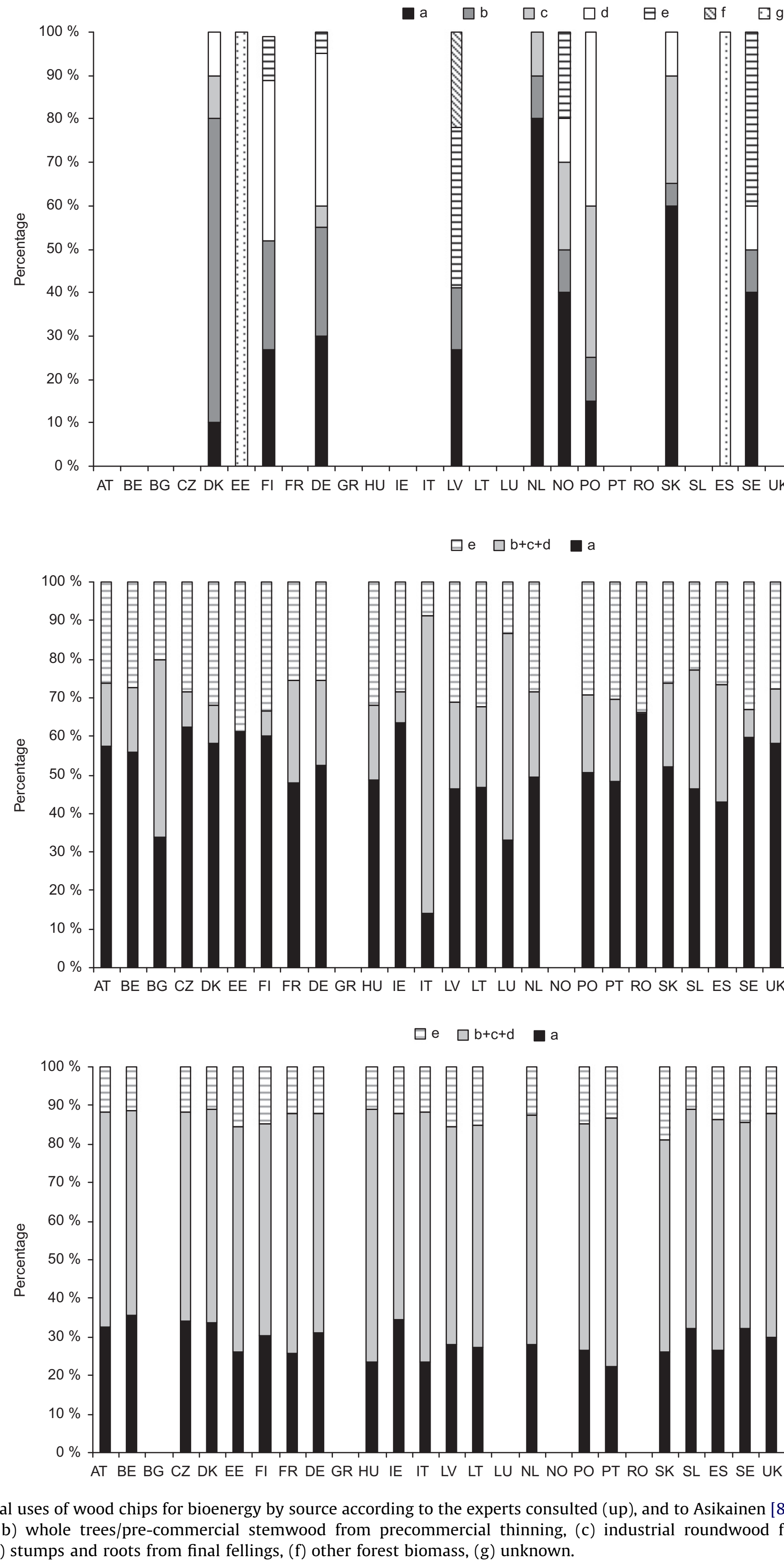

Fig. 6. Total estimated potential uses of wood chips for bioenergy by source according to the experts consulted (up), and to Asikainen [8], and Karjalainen [6]. (a) Logging residues from final fellings, (b) whole trees/pre-commercial stemwood from precommercial thinning, (c) industrial roundwood from final fellings, (d) industrial roundwood from thinnings, (e) stumps and roots from final fellings, (f) other forest biomass, (g) unknown.

person (c. 2 M solid m^3). In this case, the differences were due to different accounts, as the data of the present use of forest chips included also wood waste.

According to the data analysed, most of the harvested wood for bioenergy comes from final fellings, which explains the importance of logging residues as a source of raw material [8]; and the

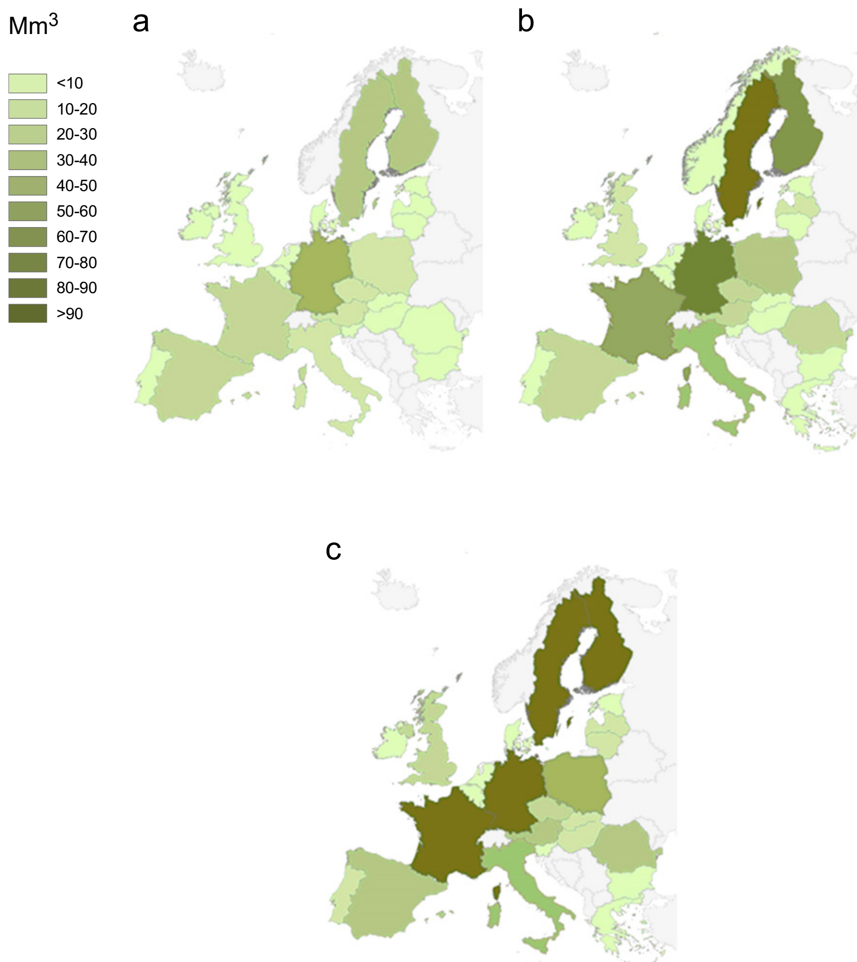

Fig. 7. Average estimates of forest wood biomass potentials in Europe (M m^3). (a) Above ground biomass, current conditions, (b) total biomass, current conditions, (c) total biomass, highest potential.

pre-commercial thinnings are, in general, less used because of the low profitability of the operations. On the other hand, there are some limitations for the development of forest residues as an energy resource. Primary residues have been limited, for example, by the use of industrial residues because they are cheaper and easier to access [2]. But this is not the only factor: also the traditional markets for wood-based products determine also the amount of forest residues [8], the competitiveness with other industrial uses like e.g., paper, roundwood and pulpwood: and the fact that this source is at the beginning of its development in most of the countries studied.

Few countries consider stumps as one of the main sources for forest fuel according with the estimates provided, including: Finland, Sweden, UK and Germany. In the latter, the results estimate 5% of the wood chips resulting from the use of stumps. Even though the use of stumps for energy purposes it is not the only benefit for this kind of harvesting. Growth and stand productivity are positive affected by stump removal, or does not differ significantly [41], could be a way to promote post-harvest operation, improving site preparation for regeneration [3], reduce the root rot infection of the new stands [42] and could represent a potential business sector, as in the Finnish case [37]. However, the limited current use of stumps may be explained due to site suitability limitations, under-developed power plant technology in small-scale plants [37], some standards in certified forests that omit or limit soil preparation (Denmark) or scarification (Germany, Luxembourg, Sweden), and in consequence impeding stump harvesting [42]; and finally due to social perceptions and attitudes.

Concerning procurement, the analysis of the data retrieved shows similar procurement chain in some countries, despite the fact that they present different forest characteristics and are in fairly different geographic locations. For example, the procurement of logging residues follows similar procurement chains in the case of the Nordic countries as well as Estonia, Latvia and Germany. In general, countries with well established use of forest chips for energy follow more advanced technologically alternatives than the countries with less use.

This uneven development of present use of forest chips for fuel is also reflected in the availability (or absence) of sources of information concerning prices. The prices reported by the experts are on the same range that prices provided by the European Bioenergy Networks [43,44] for Austria, Denmark, Poland and Sweden, although there correspond to different years. Exceptions are Estonia, where reported prices were much lower (reported 5 EUR/MW h compared to 14.5 EUR/MW h), and in Finland, where there were higher (18.8 EUR/MW h compared 9.8 MW h). It must be taken into account that there is a large regional variability as well as seasonal variability [44], and many countries have emerging markets not enough developed to have official statistics.

Concerning potentials, the data shows an overall agreement between the figures provided by the experts and the data found in the secondary sources included. Some relevant differences were found, despite the studies reviewed were based in similar methodological approaches. For instance, in the case of Poland and Spain, the disagreement was between the figures provided by the experts and the data extracted from the literature, and in

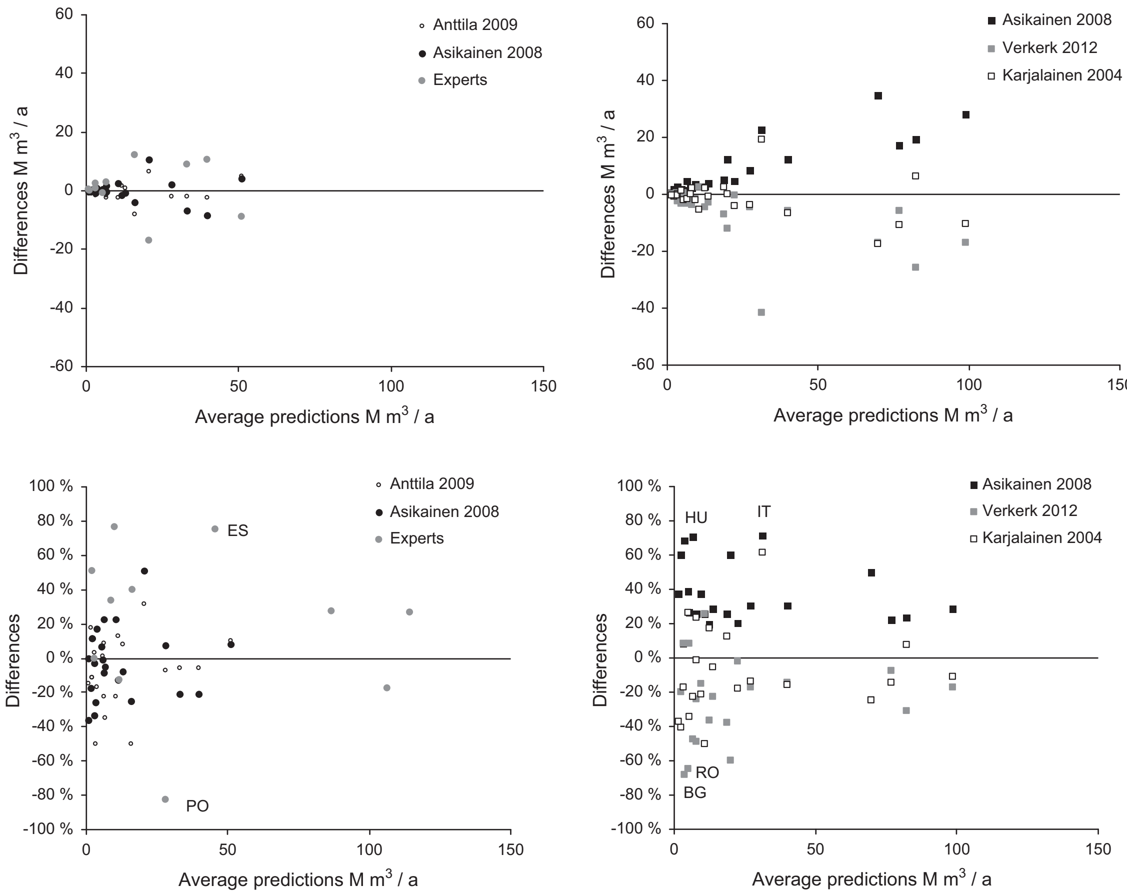

Fig. 8. Comparison of country estimates for potential of forest wood biomass for bioenergy considering: above ground biomass (left) and total biomass (right). The estimates are for current scenarios, based on the data retrieved from independent experts and literature sources. The scores refer to the differences between the estimate and the average of the sources, expressed in M m^3/a (up) and as a percentage of the average (down). The initials correspond to the highest deviations in percentage (ES: Spain, PO: Poland, IT: Italy, HU: Hungary, BG: Bulgaria, RO: Romania).

Italy, Hungary and Romania, between the different studies compared. These divergences can be attributed to different assumptions of resources available for harvesting due to technical limitations (e.g., slopes), or to alternative sources of data concerning utilization, allocation and growth of the forest resources.

Finally, the comparison of the current uses of wood chips with the overall above ground forest biomass potential under current conditions (Ia) suggest a general under-utilization of wood chips as a resource for energy, with the exception of Denmark and Estonia (using 71% and 65%, respectively). Austria, Finland and Sweden are about 15%, 14% and 13%, respectively, and the rest of the countries with data available, are below 6% of the potential estimated. This implies a huge development of the sector to be expected in the middle term, if the economic as well as technological conditions are fulfilled.

5. Conclusions

The results of this study reveal that many countries have similar procurement chains despite the different forest characteristics and location, significant volumes of forest chips are already used in most of the selected countries for energy, and seems that this early establishment shapes the technological complexity of the supply chains. The consulted experts see, however, that even larger volumes can be mobilized and novel technology developed to improve the efficiency of supply. In the EU, there are large potentials of forest biomass for energy that are largely under-utilized. Averaged estimates for biomass potential for energy available under current conditions were 277 M m^3, for above ground biomass and 585 M m^3 for total biomass. The total long term potential is estimated to be 913 M m^3.

This research, with its obvious limitations, can serve as a valid overview of the current situation of the procurement of forest chips for energy in Europe, and can be useful to identify future research efforts in the field. It also points out the need of further studies to complement and expand the research to other countries and to contribute to standardised estimates of procurement methods, demand and potentials, of wood energy supply.

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